# Calibration of Density Diagnostics for Solar Physics Using an Electron Beam Ion Trap

Completed Technology Project (2016 - 2019)

## Project Introduction

We propose to use laboratory measurements to calibrate spectroscopic electron density diagnostics relevant for solar physics to accuracies of better than 20%. Our results will be directly applicable to solar spectroscopy and can also be used to test theoretical calculations. Improving the accuracy of density diagnostics will increase the scientific return of current and planned solar missions such as Hinode, SDO, Solar Orbiter, Solar-C, and sounding rocket observations such as EUNIS. This work will address the Laboratory Nuclear, Atomic, and Plasma Physics element of the Heliophysics Technology and Instrument Development for Science program. Density is a key parameter for solar physics. It is used to determine the energy and force balance in various solar regions and to understand the nature of solar structures. Among the numerous areas in which accurate density measurements are needed are coronal heating, coronal seismology, coronal mass ejections, solar flares, and understanding the nature of inhomogeneous structures in the solar atmosphere. The primary density diagnostics for solar plasmas use ratios of emission line intensities, at least one of which is density sensitive. This sensitivity arises due to the atomic physics of the system. It depends on the collisional excitation and deexcitation rates and radiative transition rates for the several atomic levels directly involved in the transition, as well as cascade contributions from many higher energy levels. Essentially all of these data comes from theoretical calculations, which have not been adequately tested. The theoretical results are usually compared to other calculations or to observed solar spectra, neither of which independently tests the theory. Moreover, the calculations rarely provide any uncertainty estimates and large systematic errors are possible depending on the complexity of the atomic model used. A recent comparison of several diagnostic line ratios showed discrepancies in the inferred density of factors of 2 to 10. This implies that observations are unable to accurately interpret spectra in order to describe solar structures, which severely limits our ability to model the underlying physics. Our measurements will reduce the uncertainty of density diagnostics by an order of magnitude. We will calibrate density sensitive line intensity ratios using the Electron Beam Ion Trap (EBIT) at the Lawrence Livermore National Laboratory. EBIT is a cylindrical trap, in which an axial magnetic field guides an electron beam running along the axis. The electron beam forms an electric potential well that confines the ions in the radial direction, while biased electrodes at each end provide axial confinement. Collisions between the ions and the electron beam ionize and excite the trapped ions. By adjusting the electron beam parameters we can vary the density in the trap and measure how the various line intensity ratios change. The ion emission line spectra will be measured using high resolution ultraviolet spectrometers. The electron beam density will be derived from the electron current and X-ray or extreme ultraviolet images of the beam. The effective density experienced by the ions depends on the overlap of the ion cloud with the electron beam. To determine the overlap, the geometry of the ion cloud will be measured using an optical CCD. The resulting effective electron density will range from 1E8 to 1E13

Image Not Available

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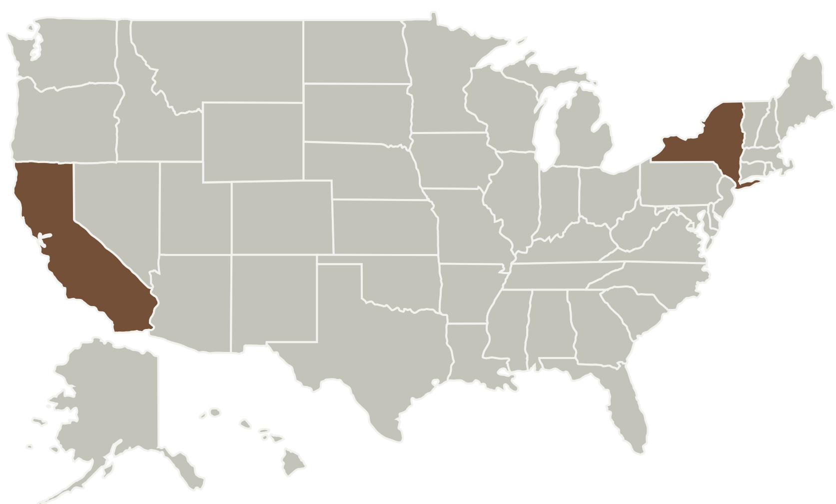
cm-3. We will also compare our results to new theoretical calculations and to published atomic data in order to identify the underlying causes of any discrepancies we find. We will concentrate on ions most relevant for solar physics. For example, we will measure diagnostics from Fe IX - XIII found in the 170-210 Angstrom wavelength band, as these lines and wavelengths are observed by various solar spectrometers. We will also measure diagnostic line ratios from other ions and wavelengths that are important for specific instruments.

### Anticipated Benefits

Support NASA's strategic objectives to understand the Sun and its interactions with Earth and the solar system, including space weather. This will be achieved by developing/demonstrating instrumentation technology necessary to address the following science goals:

- Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system;
- Advance our understanding of the connections that link the Sun, the Earth, planetary space environments, and the outer reaches of our solar system;
- Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

### Primary U.S. Work Locations and Key Partners



## Organizational Responsibility

**Responsible Mission Directorate:**

Science Mission Directorate (SMD)

**Lead Organization:**

The Trustees of Columbia University in the City of New York

**Responsible Program:**

Heliophysics Technology and Instrument Development for Science

## Project Management

**Program Director:**

Roshanak Hakimzadeh

**Program Manager:**

Roshanak Hakimzadeh

**Principal Investigator:**

Daniel W Savin

**Co-Investigators:**

Michael Hahn
Peter Beiersdorfer
Heather Horgan
Gregory V Brown

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| Organizations Performing Work | Role | Type | Location |
|---|---|---|---|
| The Trustees of Columbia University in the City of New York | Lead Organization | Industry | New York, New York |

| Primary U.S. Work Locations | |
|---|---|
| California | New York |

## Technology Maturity (TRL)

Start: **4**
Current: **4**
Estimated End: **5**

1 2 3 4 5 6 7 8 9

Applied Research | Development | Demo & Test

## Technology Areas

**Primary:**

- TX08 Sensors and Instruments
  └ TX08.3 In-Situ Instruments and Sensors
    └ TX08.3.1 Field and Particle Detectors

## Target Destination

The Sun